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A SUMMARY OF WAVE DATA NEEDS AND AVAILABILITY.(U)
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A Summary of Wave Data Needs and Availability

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Ship Research Committee

Maritime Transportation Research Board

Commission on Sociotechnical Systems

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A SUMMARY OF WAVE DATA NEEDS AND AVAILABILITY

A Report Prepared

by

AN AD HOC ADVISORY COMMITTEE ON WAVE DATA

of the

SHIP RESEARCH COMMITTEE

of the

Maritime Transportation Research Board

Commission on Sociotechnical Systems

National Research Council

National Academy of Sciences
Washington, D.C.
August 1979

NOTICE: The project that is the subject of this report was approved by the Governing Board of the National Research Council, whose members are drawn from the Councils of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine. The members of the Committee responsible for the report were chosen for their special competences and with regard for appropriate balance.

This report has been reviewed by a group other than the authors according to procedures approved by a Report Review Committee consisting of members of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine.

This report was prepared for the interagency Ship Structure Committee, consisting of representatives from the Military Sealift Command, the U.S. Coast Guard, the Naval Sea Systems Command, the Maritime Administration, the American Bureau of Shipping, and the U.S. Geological Survey, and is submitted to the Commandant, U.S. Coast Guard, under provisions of Contract DOT-CG-80356-A between the National Academy of Sciences and the Commandant, U.S. Coast Guard, acting for the Ship Structure Committee.

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BACKGROUND

In 1977, the Ship Structure Committee (SSC) published report SSC-268, Environmental Wave Data for Determining Hull Structural Loadings, by D. Hoffman and D.A. Walden. The recommendations contained in that report are included as an appendix to this paper. After considering these recommendations the SSC requested the Ship Research Committee (SRC) of the National Academy of Sciences to develop a paper that would summarize the wave data needs of designers of wave-loaded structures to inform wave data collectors of the uses for such data and the general coverage and form desired. This paper is the response to that request.

The paper consists of three parts. First is a summary of the wave data needs of three classes of maritime interests: (a) designers of ships and floating and fixed offshore platforms, (b) regulatory bodies and classification societies primarily interested in safety and environmental protection, and (c) operators concerned with ship routing and offshore activities such as oil and mineral recovery and energy production. The second part is a summary of the status of wave data, and the third part is a set of conclusions.

USER NEEDS FOR WAVE DATA

Ship Design

Until a statistical or probabilistic approach was taken, the random and variable nature of the seaway defied efforts to develop the quantitative descriptions needed to apply the basic laws of hydrodynamics to the prediction of forces on ships and other wave-loaded structures. Since 1953, when St. Denis and Pierson's paper "On the Motions of Ships in Confused Seas" appeared in the SNAME *Transactions*, dynamic, probabilistic treatment of the seaway and ship response has advanced rapidly. Mathematical models of the seaway, models relating the seaway to wind fields, and mathematical models of ship response to wave loading are still evolving. Such models permit estimates of values of wave height that define the design bending moment in ships and maximum loads on other ocean structures. These also permit treatment of other wave components of the seaway that produce vibratory responses in ships and floating and fixed structures that

are important in the consideration of fatigue. The common denominator in all this is a spectral representation of the seaway that defines the distribution of wave heights against the frequencies and directions of the component waves.

The traditional method of assessing ship strength involves poising the ship statically on a "standard" wave of length equal to the ship length. The calculated hull-bending stresses provide a means of comparison with previous ships, and a large body of experience provides, in effect, a data base for judging adequacy. This is a valid approach as long as the range of experience, in terms of ship size, speed or configuration, is not exceeded. Very large ships, high-speed ships, hydrofoils, surface-effect ships (SES), multihulls, floating platforms (e.g., offshore thermal energy conversion platforms--OTEC) that lie outside the range require a different, more sophisticated approach to structural design, if a realistic answer is wanted.

When considering the question of what practical use will be made of an improved and more comprehensive wave data bank, the design of the next generation of LNG ships comes to mind. The enormous amount of flared gas going to waste in the Middle East remains a tremendous energy resource potential that should soon have a profound effect on LNG shipments.

Although present classification society rules for strength cover current standard 125,000 cubic meter class LNG ships, they are not entirely satisfactory. Ships in the 300,000 cubic-meter class now on the drawing boards have similar overall dimensions of length and beam to ultra-large crude carriers; however, their finer lines and greater speed will cause them to respond differently to wave loading.

A phenomenon that is emerging as important in large Great Lake bulk carriers and may be significant also in large, high-speed ships, such as LNG carriers, is that of 'springing.' In some cases the amplitudes of springing can be large, and hull bending stresses approaching the level of those induced by wave bending have been observed. In the lifetime of a ship, the number of stress reversals in springing could conceivably be large enough to approach fatigue failure limits.

Rational design of hull structure for strength, fatigue, and deflection and design of cargo tanks against sloshing and other dynamic forces, depend directly on loadings and motions derived from known critical sea-state energy spectra.

Even for conventional ships that lie within the range of experience, the press for design refinement to save weight and improve the deadweight/displacement ratio, fuel

consumption, and speed requires realistic wave-load data. For all ships, the study of fatigue, slamming, and wave-induced vibratory stresses requires a description of the magnitude, frequency, and distributions of waves the ship may be expected to encounter.

Floating and Fixed Structures Design

Although, to date, most operational and planned offshore mining operations have used ships, large and unshiplike floating structures are being designed for offshore oil drilling, mining, and energy conversion. Precise positioning and motion prediction or control require a reliable description of the wave environment. A good example is the OTEC project, where concepts involving pipes 3000 feet long and 50 feet in diameter suspended from a large floating structure obviously require careful dynamic analysis of the wave-induced motions, forces and structural response.

The designers of fixed offshore structures use wave data somewhat differently from ship designers, but they need a similar spectral description of the seaway. Their concern with wave heights relates first to the selection of platform clearance above the water surface with respect to the highest wave to be reasonably expected, e.g., the "100-year wave." The designer of fixed structures and the designer of stationary floating structures are concerned with wave drag forces exerted on the legs and cross members of such structures, whereas the ship designer is more concerned with buoyancy forces and rigid-body added mass and damping. Because offshore structures are designed to have long service lives, wave-induced fatigue is an important consideration for structural elements having natural frequencies of vibration corresponding to frequencies of component waves that contain significant energy. In addition to the direct interaction of waves and structures, the designer of fixed structures may also have to take into account the interaction of waves with foundation soils and forces on structures exerted by wave-induced motions of ice.

Other Design Uses

The same sort of wave data required to design marine structures is needed for motion analyses of ships and floating platforms and design of associated control systems, e.g., shipborne aircraft landing systems, fire-control systems, crane ship operations, and control systems and ride prediction for hydrofoils and surface effect ships.

Shallow-water wave characteristics and an understanding of wave action and currents in the surf zone are clearly

important in the study of beach erosion and the design of harbors, entrance channels, breakwaters and shore-front structures for the berthing of ships or the protection of adjacent land areas.

Use by Regulatory Bodies and Classification Societies

Regulatory bodies and classification societies concerned with safety and environmental protection use wave data in much the same way as the structural designer. Indeed, much pioneering work in the analysis of wave loading of ships and other marine structures has been done by the classification societies.

Use by Operators

Wave forecasting is a growing area of activity that serves ship operators and offshore oil, mining, and energy interests. Much of the work that has gone into the development of forecasting and hindcasting techniques has been stimulated by operational needs.

Table 1 summarizes the range of wave-data users and their principal areas of interest.

Coverage

Because it is patently impractical to fully characterize the seaway for all ocean areas, some sort of priority must be established for obtaining the desired coverage of those areas of interest because of shipping or ocean engineering activity. (See Appendix A.) Data already exist in varying amounts and quality for certain ocean areas, seas and lakes. Table 2 gives, in a coarse way, the availability of wave data for the principal areas of interest.

In Table 2, "observed data" refers to observations taken aboard ships at sea. These are routinely reported in a standard format to NOAA. Wave height, period, and direction are "eyeballed", so the data are necessarily approximate. It is primarily useful in making estimates of long-term distributions of wave height and period. "Measured data" refers to spectra derived from *in situ* measurements of wave height, usually in the form of a continuous trace of wave height against time, taken on a weather ship, buoy, or fixed structure. These data take long periods to accumulate and then must be converted to spectral form, which requires considerable computer time and insight on the part of the processor to ensure reliable output. "Hindcast data" refers to spectra generated by a mathematical model using atmospheric pressure fields to compute wind fields, which

TABLE 1. U.S. USERS AND THEIR PRINCIPAL NEEDS FOR WAVE DATA

USERS	PRINCIPAL AREAS OF RESPONSIBILITY OR INTEREST			
	SAFETY, STRUCTURAL ADEQUACY	ENVIRONMENTAL PROTECTION	OPERATIONAL EFFECTIVENESS	RESEARCH AND DEVELOPMENT IN APPLICATION OF WAVE LOADING
DESIGNERS				
Commercial Ship Design Offices	X		X	
MarAd Ship Design Offices	X	X	X	
USCG Design Office for USCG Ships	X		X	
USN-NAVSEA Ship Design Division	X		X	
Commercial Offshore Structure	X		X	
REGULATORY AND CLASSIFICATION BODIES				
USCG Merchant Marine Technical Office	X	X		X
USGS Verification Office, Conservation Division	X	X		X
USA Corps of Engineers		X		X
American Bureau of Shipping	X			X
OPERATORS				
MarAd Research and Development Office			X	X
Petroleum Industry	X		X	X
Offshore Mining and Energy Interests	X		X	X
Ship Forecasting and Routing Services			X	
RESEARCHERS				
David Taylor Naval Ship Research and Development Center			X	X
Universities and Private Laboratories				X
US Army - Coastal Engineering Research Center		X		X
US Army - Waterways Experiment Station		X		X

TABLE 2. WAVE-DATA COVERAGE

PRINCIPAL AREAS OF INTEREST	OBSERVED DATA	MEASURED DATA (SPECTRA)	HINDCAST DATA (SPECTRA)
North Atlantic	Good	Poor	Good
North Atlantic Coastal	Good	Poor	Poor
South Atlantic	Poor	Negligible	Negligible
South Atlantic Coastal	Poor	Poor	Negligible
Carribean & Gulf of Mexico	Good	Poor	Good
Great Lakes	Fair	Poor	Fair
North Pacific	Fair to Good	Poor	Good
North Pacific Coastal	Good	Poor	Poor
South Pacific	Poor	Negligible	Negligible
Indian Ocean	Poor to Fair	Negligible	Negligible
Mediterranean	Good	Negligible	Good
South Africa Coastal	Fair	Negligible	Negligible
North Sea	Good	Fair	Good

are the principal inputs. These depend on adequate measured wave data and associated atmospheric conditions to verify the parameters in the model.

Although generally not addressed directly in design, ships occasionally encounter abnormally large, steep seas, referred to variously as "freak," "rogue," or "episodic" waves. These develop in certain locations because of interaction of wind, swell, and currents. Very little information is available on these waves beyond eyewitness descriptions. A common feature of such descriptions is that of encountering a deep steep trough followed by a single high steep wave. Huge waves of this type occur under certain conditions off the eastern coast of the Cape of Good Hope. In this region, storm swells traveling northeastward from the Antarctic and reinforced by local gale winds produce high seas that may be further augmented and steepened over the continental shelf. When these encounter the southward flowing Agulhas Current, extremely steep and high waves can develop; the "episodic" wave is believed to be a product of such a combination. A number of cases of severe damage or loss of large ships to such waves have occurred--e.g., the loss of the tanker World Glory. The Gulf Stream off Cape Hatteras, the Gulf of Alaska, the English Channel, and the Bay of Biscay are some of the other areas where storms and currents combine to produce abnormally high, steep waves.

Designing to resist such extreme seas may be infeasible and the most practical way to deal with them may be avoidance. In either case, data on these waves and the conditions that spawn them are needed to assess the potential for extreme loads and to make possible the prediction of occurrence, duration, and severity for avoidance.

Currents, their interaction with waves and the subsurfce wave profiles that result, are also important in the design of offshore structures.

Spectra

Current design uses the "point" or nondirectional spectrum and, except for a few directional spectra, all available measured spectra are point spectra. Directional spectra describe the distribution of wave energy as a function of direction as well as frequency. Because of the cost and difficulty of measurement, very few directional spectra have been obtained. In order to completely describe the performance of a ship in a seaway, the designer would like to have directional spectra, and such spectra are now becoming available by hindcasting. The added parameter considerably complicates the matter of data archiving.

Study is needed to evolve a suitable format for dealing with directional wave spectral data.

The shapes of actual spectra are only approximated by mathematical spectra. The ISSC two-parameter spectrum, which is characterized by the significant wave height and average wave period, is widely used. These parameters can be correlated with the average wave heights and periods routinely reported by mariners. The accumulation of these visually observed heights and periods provide a picture of the long-term distribution of these parameters for various ocean areas. These coupled with mathematical spectra permit estimates of extreme values to be made.

Recently multiparameter formulations, such as a six-parameter formulation by Ochi, have been proposed that allow actual spectral shapes to be more closely approximated mathematically. The improved definition of the high-frequency "tail" of the spectrum that is afforded by this type of formulation will be helpful in the analysis of springing in ships and the vibratory response of structural elements in other structures. The JONSWAP project has compiled much North Sea wave data and proposed a multiparameter spectrum that has gained wide acceptance.

WAVE DATA STATUS

Visual Observations

Mariners have been observing and reporting wave and other environmental conditions for many years. Individual observations of wave conditions may over- or under-estimate wave heights and periods. However, these errors tend to average out over many observations, and the total presents a statistically acceptable picture of the long-term distribution of significant wave heights and average periods. As part of a World Meteorological Organization shipboard data collection effort, the National Oceanic and Atmospheric Administration (NOAA) supports a large-scale cooperative vessel-of-opportunity program. Through this program, which is augmented by Navy and Coast Guard data, approximately 1900 marine observations (including visually observed wave direction, height, and period) per day are available worldwide, principally along the major shipping routes. NOAA's National Climatic Center maintains a file of these visually observed sea, swell, and wave data as part of a collection of meteorological observations from most of the marine meteorological sources in the world.

Measured Waves (in situ)

In order to derive spectra, at least 20-minute continuous records of wave height versus time are needed. Typical of such data are the records taken by British weather ships in the North Atlantic, e.g., the station "India" data. Most in situ measurements of deep-water waves in the future will probably be taken by buoys. It is noted that no wave measurements beyond the continental shelves are being taken or currently planned by any U.S. agencies. NOAA's Data Buoy Office is testing a buoy capable of measuring directional wave spectra. Work continues on shipboard height sensing devices, which along with the associated motion measurements are the key to a shipborne wave-height measuring system, but no satisfactory system is in hand as yet. In situ measurements cannot provide enough coverage to develop a worldwide wave climatology. A primary role of in situ measurements now appears to be to supply detailed, accurate actual wave data that can be used to verify or calibrate other methods capable of providing the needed global coverage, i.e., hindcasting and satellite wave-measuring techniques. The NOAA data buoy program is confined to U.S. coastal waters. At present, 19 buoys are deployed--7 on the east coast, 3 in the Gulf of Mexico, and 9 on the U.S. west coast, including the Gulf of Alaska. Most of the buoys are capable of recording wave data twice daily in 12 to 50 frequency bands, from which significant wave height and average wave period are derived and made available over meteorological communications circuits. The information recorded from the buoys is forwarded to the National Oceanographic Data Center for further dissemination.

The U.S. Army Corps of Engineers is concerned with the design and effectiveness of shoreline structures to minimize damages to civilian works and to beaches. In support of this work, the U.S. Army's Coastal Engineering Research Center has a small wave-gauging program on the U.S. east coast and plans a major wave-measurement program along the California coast.

A coastal wave-monitoring program under development at NOAA is in part a cooperative effort involving other federal agencies. The program, initiated largely in response to requests from the U.S. Geological Survey and the Corps of Engineers, includes:

- Plans for hindcast model verification;
- Use of these models to predict extreme-wave conditions;

- Measurements using small "waverider" buoys (developed by the Dutch) and instrumented offshore platforms;

- Support for research and development of coastal wave monitoring radars;

- Provision of real-time wave data for marine forecasts; and

- Development of wave-data archives for various applications.

It should be noted that different users have different needs with respect to wave data and models and that the models and verification aspects are tailored for specific uses.

Potential sources for wave data to augment the coastal wave monitoring program are the offshore developers, who are required by law to collect wave data off the Atlantic coast in conjunction with exploratory drilling operations. These data are proprietary, but the developers are required to make them available to USGS and they will ultimately become public.

The National Oceanographic Data Center has developed formats for archiving both raw and analyzed measured wave data along with supporting meteorological and ocean current data for the same time and location. The formats have been reviewed within NOAA and are presently being reviewed by major wave-data collectors in the United States.

The Army Coastal Engineering Research Center, in support of the planned expansion of its coastal-wave data-measurement system, is working with an Ocean Wave Statistics Subcommittee of the American Society of Civil Engineers and various federal agencies on the development of standard formats for sampling, record length, observational frequency, measurement units, and raw-data formats for the archiving of coastal-wave data.

The Institute of Ocean Sciences, Wormley, England, following an offer to become the worldwide Responsible National Oceanographic Data Center for Waves under the Intergovernmental Oceanographic Commission, has developed a format under its Marine Information and Advisory Service for inventorying world wave data obtained from in situ measurements.

Satellite Wave Measurements

Wave data collection by satellite offers the potential for developing a worldwide wave climatology. Satellite

measurement techniques are still in the developmental stage, and production of useful data is several years away. Since April 1975, the GEOS 3 satellite has been measuring wave heights along its track by means of a radar altimeter to about ±0.5 meter accuracy and covering an instantaneous area averaging approximately 5 km^2. SEASAT A, which was launched in July 1978, was expected to obtain radar altimeter wave-height measurement to an accuracy of about ±0.25 meters. About 100 days of data were recorded before the failure of SEASAT A; these data have undergone only a limited evaluation. Additional "proof of concept" measurements taken by SEASAT A were wave length by means of a synthetic aperture imaging radar wind speed by a microwave radiometer, and wind direction and speed by means of a microwave scatterometer. In spite of the limited nature of the data obtained in the 100 days of SEASAT A operation, the output is reported to be encouraging. This information will be useful in the development of a National Ocean Satellite Program for the early 1980s that is now in the planning stage. SEASAT A measurements of wind and waves will also be useful in a verification program for the hindcast wave-spectra effort. However, "ground truth" data, representative of the wide range of oceanic wind and wave conditions, must be collected and used to establish the credibility of the satellite sensor systems.

The potential for obtaining wind direction and speed data as well as wave-length spectra in the southern hemisphere may eventually facilitate the development of wave spectral data for the oceans south of the equator. The resolution limitations for wave-length measurements (50 feet or greater) and the limited success to date with satellite wind measurements impose problems. However, the combination of measurements that have been made on SEASAT encourage the belief that worldwide wave spectral data may be obtainable in future satellite measurement programs.

Although the Space Data Center of the National Satellite Center has been considering the problem of archiving satellite-derived wave data, as yet no system has been established to accomplish this.

Hindcast Wave Spectra

The Fleet Numerical Weather Central (FNWC) of the U.S. Navy is presently computing a hindcast wave spectra utilizing historical pressure patterns over the northern hemisphere. Directional wave spectra (12 directions and 15 frequencies) are compiled for three hourly intervals at grid points spaced approximately 200 miles apart. To date, 11 years of North Atlantic and 12 years of North Pacific hindcasts have been computed, with an additional 4 years anticipated for each ocean under the present effort. The

need for more years of effort beyond this will be evaluated. The FNWC is currently testing an improved analysis and prediction model that deals with wave propagation in as many as 24 directions at 15° increments. A doubling of the number of directions of propagation (12 to 24) can double the computer time and, therefore, must undergo careful consideration prior to implementation on an operational basis.

The Navy is in the process of preparing a wave spectra atlas that is expected initially to be based on 5 years of computed wave spectral data in the North Atlantic Ocean. The atlas is expected to address wave-hindcast model verification and to summarize spectral data in terms of height versus period, primary wind direction versus height, primary wave direction versus wind direction, persistence, etc. Present plans call for initial availability in 1979.

FNWC intends to archive the results of the hindcast wave-spectral program in a tape format. NOAA is considering including the Navy wave spectra as part of the National Oceanographic Data Center data library.

The Corps of Engineers is also developing a directional wave spectral atlas, based on 26 years of augmented pressure-derived wind data, to meet its specific needs in coastal waters. The program is designed to provide wave spectra for 169 locations along the east coast of the United States in about 50 feet of water. The program starts in deep water with computation at 100-mile grid spacings and at 6-hour intervals. Over the continental shelf, grid spacings of 10 to 90 miles are used in 3- to 6-hour computations. In the near shore from 50 feet deep to the beach, 10-mile grid intervals are to be used at time intervals of 1 to 3 hours.

The North Atlantic coastal wave spectral atlas is expected to be completed in late 1979 and that for coastal waters of the North Pacific at a later date. Although the program has been designed to provide statistics for the coastal waters, computed directional wave spectra for each of the ocean basins are a prerequisite and should be useful to the marine community.

The Army hindcast wave spectral program has not progressed to a point where archiving standards have been resolved; however, it is intended to archive all the useful data generated in the program.

Forecast Wave Spectra

The Navy currently has an operational wave-spectral analysis and forecasting program at FNWC in Monterey. Under this program, analyses and predictions of directional wave

spectra are produced at 12-hour intervals for the northern hemisphere oceans. The program has been in use for about 4 years. Data resulting from the program are archived at FNWC.

Verification

The wave-spectral model used by the Navy FNWC has undergone a variety of verification efforts over the past decade. Most of which were comparisons with point spectra. Prominent among these was a 6-month effort that involved comparisons with NOAA wave-spectral measurement data. More recently, measured waves and analyzed and predicted waves have been compared during instrumented sea trials and wave-rider measurements in cooperation with the Netherlands. A 2- to 3-year program in cooperation with the Coast Guard and MarAd will be started in 1979. The ship USNS Furman will be instrumented to record response under a variety of conditions for transits between the U.S. west coast and the western Pacific. NOAA data buoy wave measurements will be used for verification with each ship passage. Further systematic verification is required. For this purpose, it is important to identify a network of ground truth stations that are reasonably represenative of the wide range of wave conditions that can occur over the oceans of the world. A recently developed directional spectra sensing capability by the NOAA Data Buoy Program can be useful in providing the means of verifying the wave spectra model.

CONCLUSIONS

1. The recommendations for research and the priorities proposed in SSC-268 (Appendix A of this report) are endorsed.

2. The principal wave-data producing agencies in the United States are

   - NOAA (ocean and continental shelf);
   - U.S. Army Corps of Engineers (coastal);
   - U.S. Navy Fleet Numerical Weather Central (ocean and continental shelf);
   - U.S. Coast Guard (Great Lakes); and
   - Offshore developers (continental shelf; data proprietary).

3. The present wave data base to meet the developing needs of designers of ship and offshore structures, regulatory

bodies, and operators is incomplete. To complete it using only *in situ* measurement methods such as buoys appears impractical. However, these do have important use in the collection of data for special areas of interest, particularly where severe seas are known to occur, and for verification and calibration of hindcast and satellite measurement techniques. The two most promising means of developing the required wave climatology appear to be (a) by hindcasting techniques and (b) by satellite observations. Hindcasting techniques, which can produce broad-band directional spectra, are well advanced but require additional verification. Satellite techniques and hardware will not be available for some years. In view of the loss of SEASAT, early establishment of a wind- and wave-sensing satellite is encouraged.

4. Visual observations by mariners continue; although these observations cannot provide quantitative (spectral) data, they are valuable for estimating long-term wave-height distribution.

5. Present formats for reporting visually observed data appear adequate. For measured data, for which automatic data processing methods are now common, there appears to be no pressing need for initiatives to develop special formats.

6. There is a need for a format for archiving directional spectra, which are becoming available via hindcasting.

7. The amount of wave data that will be produced by satellite sensors is potentially enormous. The matter of how it can be managed, analyzed, archived, and retrieved and by whom needs to be addressed.

8. Linked with the problems of managing, archiving and analysis of the large masses of wave data that hindcasting and satellites are expected to produce is the need to reduce this information to useable families of spectra that will correctly represent long-term wave conditions to serve the practical needs of users such as designers and regulatory bodies.

9. The quantity, type, and distribution of proprietary wave data are unknown, but this is possibly an important data source.

10. Quantitative statements regarding required accuracy of measurements and range of frequencies to be measured will require further research. In particular, the high-frequency portions of sea spectra, which are important in fatigue, need definition.

11. Development of a satisfactory shipborne wave-height sensing system is still not in hand. Such a system would allow much-needed measured wave data to be acquired in shipping lanes to support the needs of ship designers and operators.

12. The conditions that lead to the occurrence of abnormal waves, such as those that occur off the southeast coast of Africa, need to be researched.

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APPENDIX

From SSC-268, Environmental Wave Data for Determining Hull Structural Loadings, by D. Hoffman and D.A. Walden

II. A RESEARCH PLAN

General

One of the principal objectives of this project was to develop a research plan for the acquisition of required additional ocean wave data, and their translation into a form useable by hull structural designers. On the basis of the survey given in the following chapters, recommendations for short and long-range research are given here. In addition to the proposed research projects themselves, however, consideration should be given to setting up a central management or coordinating project to oversee the acquisition of data for use by naval architects. One object would be to keep all interested parties informed as to what projects are being undertaken and who is sponsoring them.

Some of the projects listed below could produce immediately useful data if undertaken promptly, while others would not be productive for some time. A discussion of recommended priorities is given at the end of the chapter.

Hindsight Techniques

1. Evaluation and refinement of existing wave hindcast programs. The only suitable procedure in active operation is that of the Navy Fleet Numerical Weather Central (FNWC) in Monterey. A continuing, routine checking and verification process should be carried out, comparing hindcast spectra with those calculated from wave measurements at data buoys or weather ships. As improvements in the hindcast procedures are made, they should be evaluated by this continuous routine checking. It is understood that such checking is now being done by FNWC to some degree.

From the long-range viewpoint, attention should be directed to private forecasting and hindcasting procedures (such as that of Ocean Routes, Inc., Palo Alto, California) which are being developed to serve oil well drilling activities but could perhaps be extended to serve shipping lines.

2. Development of a comprehensive hindcast data base. After the validity of the FNWC hindcast system has been established, the data base can be developed by statistical analysis of daily spectra for at least a year at selected locations over the entire North Atlantic and North Pacific

Oceans, and in the Mediterranean Sea. Such a data base has been referred to as a "wave spectra climatology."

It should be noted that funds have already been allocated to FNWC for hindcasting directional spectra back to 1955, using the latest refinements in the hindcast model. Since this is a project of considerable magnitude, considerable effort should be devoted to improving and refining the prediction model (item 1) in parallel with this large-scale hindcasting effort.

3. Extension of the hindcast system to cover the South Atlantic Ocean and the Western Indian Ocean, including the ocean area in the vicinity of the Cape of Good Hope. After such a system becomes operational, it should be verified, analyzed and applied as in 1) and 2) above.

This project may require direct support from shipping and ship design interests, since the Navy has not given it high priority. Since a long time is required for this work, no short-term results can be expected.

Development and Use of Wave Buoys

4. Deployment of buoys. A number of buoys should be set out, with telemetered wave records regularly transmitted to shore and spectrally analyzed. See Steele (1974) for a description of the National Oceanic and Atmospheric Administration (NOAA) Data Buoy Office (NDBO) system. The buoys would be located on important steamship routes, particularly at locations where inadequate wave data are available. Resulting spectra would be used directly to increase the bank of data for designers' use.

Consideration should be given to incorporating slope, as well as vertical acceleration measurements. Such slope measurements, while not sufficient to define the directional spectra completely, can give some directional information. Cartwright (1961) discusses the limits of such slope measurements.

Tentative buoy locations:

(a) North Atlantic (Grand Banks, Faraday Sea Mount)

(b) Near entrance to English Channel

(c) North Pacific (South of Aleutians)

(d) Off South Africa.

Consideration should also be given to the possible future use of smaller moored buoys intermediate in size between the NOAA and the WAVERIDER (Dutch) buoys. However, the problem of collecting and processing the data--which has been solved by NOAA on an almost worldwide basis--must be dealt with before making practical use of such buoys. Hence, no immediate useful results can be expected.

5. Analysis of buoy data. Statistical analysis of wave spectra should be carried out in a manner similar to that described in the survey portion of this report, i.e., stratified by wave height and analyzed to obtain mean values and standard deviations of spectral ordinates. Spectra should be used directly as a basis for checking and evaluating the regular hindcast procedures discussed under items 1 and 3.

It is recognized that although this approach may be the most practical and useful for immediate problems in ship hull design, different types of analysis in order to improve the underlying theory of wave generation, propagation and decay should also be carried out for long-range usefulness.

Data from Fixed Platforms

6. Oil company data. Companies engaged in off-shore drilling operations in various parts of the world have been vigorously collecting proprietary wave data in various formats. Efforts should be made to devise a procedure for making data for areas of interest to ship operation available generally. This should be more readily accomplished when a government is involved in the data collection (as in the case of the British Government in the areas around the British Isles).

Measurement of Directional Spectra

7. Development of techniques. Further development of methods of obtaining accurate directional spectra--such as stereo photographic techniques--should be pursued, since other methods (including wave buoys, item 4) are not completely satisfactory. Such accurate directional spectra would provide the ultimate basis for verifying hindcast directional spectra.

A more long-range approach is the use of airborne synthetic aperture radars (SAR), which still requires further theoretical development. This approach can potentially provide directional spectra with a very large number of degrees of freedom per frequency band.

8. Application of directional spectra. As more data in the form of directional spectra become available, both from measurement and hindcasting, research is needed on how to describe them in a generalized format for design use. After grouping the spectra by wave height, as has been done with point spectra, it is necessary to describe the variability of wave energy with direction as well as with frequency.

Improvement in Shipboard Data

9. Analysis of weather ship data. All wave data currently being collected by the various weather ships should be regularly analyzed on a continuing basis, in a manner similar to the data from Stations I, K and P, in parallel with wave buoy and FNWC hindcasting data collection and analysis.

10. Analysis of observational wave height information. Data accumulated from ships should be analyzed for several major routes across the Atlantic and the Pacific based on the 6-hourly reports obtained by NOAA, as a means of up-dating and improving available studies. At least 2-3 years of past data should be included and the work should continue on a routine basis (as is now being done for coastal wave data).

Up-dating and extension of wave atlas publication should be encouraged, as for example the extension of Hogben and Lumb (1967) to the North Pacific.

11. Development of disposable buoy. Effort should be continued toward the development of a small buoy which can be "shot" off the side of a ship, capable of transmitting a signal for 1/2 hour when the ship is moving at 20-30 knots. Its accuracy need not be greater than that of existing small buoys. Although such a device might have its primary application to improving the quality of operational wave data, it would also provide data of value in ship design.

Satellite Systems

12. Continued development of satellite wave measurement. The enormous potential of satellite wave measuring systems dictates the continuation of efforts to develop a workable system for measuring wave spectra from spacecraft, since current efforts are only partially successful.

Priorities

The above plan covers a large number of areas for further work, with varying time frames and cost factors. The following paragraphs attempt to assign priorities to the various areas of effort on the basis of obtaining the most useful information at the least cost in the least time.

It is believed that the first priority should be given to a direct effort to obtain wave spectra for the ocean areas on important sea routes that are known to experience severe sea conditions. The most immediately available method is the use of moored buoys, as outlined in item 4.

Of almost equal importance is believed to the further verification and improvement of wave hindcast techniques, item 1, in order to prepare the way for eventual application of this approach to obtaining wave spectra for design.

At the same time, steps should be initiated that may lead to the availability of wave data in the future, as seeking oil company data, item 6.

Second priority should be given to further analysis of available data, items 9 and 10, and of new data produced by buoy deployment and hindcast procedures, items 2 and 5.

Attention should also be given to the measurement of directional spectra and their application to design, items 7 and 8.

Third priority should be given to the extension of hindcast techniques to the southern hemisphere, item 3, and to the development of new techniques for wave data collection, disposable buoys and satellite systems, items 11 and 12.

Included in this category should also be certain long-term aspects of the various research items, such as:

- New hindcast procedures (item 1)
- Development and use of small wave buoys (item 4)
- Development of airborne synthetic aperature radar (item 7).

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16. Abstract

The paper consists of three parts. First is a summary of the wave data needs of three classes of maritime interests: (a) designers of ships and floating and fixed offshore platforms, (b) regulatory bodies and classification societies primarily interested in safety and environmental protection, and (c) operators concerned with ship routing and offshore activities such as oil and mineral recovery and energy production. The second part is a summary of the status of wave data, and the third part is a set of conclusions.

The present wave data base to meet the developing needs of designers of ship and offshore structures, regulatory bodies, and operators is incomplete. To complete it using only *in situ* measurement methods such as buoys appears impractical. However, these do have important use in the collection of data for special areas of interest, particularly where severe seas are known to occur, and for verification and calibration of hindcast and satellite measurement techniques. The two most promising means of developing the required wave climatology appear to be (a) by hindcasting techniques and (b) by satellite observations. Hindcasting techniques, which can produce broad-band directional spectra, are well advanced but require additional verification. Satellite techniques and hardware will not be available for some years. Visual observations by mariners continue; although these observations cannot provide quantitative (spectral) data, they are valuable for estimating long-term wave-height distribution.

17. Key Words

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METRIC CONVERSION FACTORS

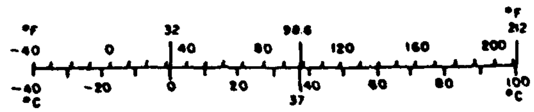
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
	AREA			
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
	MASS (weight)			
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
	VOLUME			
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
	TEMPERATURE (exact)			
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in ≡ 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.35, SD Catalog No. C13.10:286.

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
	AREA			
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
	MASS (weight)			
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
	VOLUME			
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
	TEMPERATURE (exact)			
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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Under the terms of its Congressional charter, the Academy is also called upon to act as an official - yet independent - advisor to the Federal Government in any matter of science and technology. This provision accounts for the close ties that have always existed between the Academy and the Government, although the Academy is not a governmental agency and its activities are not limited to those on behalf of the Government.

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